UDC 621.224.3+621.313.322

BULB TURBINES AND GENERATORS FOR "WESTERN YAMUNA CANAL" AND "LOWER METTUR" HYDRO ELECTRIC PROJECTS, INDIA

Akihiro Tamura
Masami Takahashi
Masanobu Yano
Satoshi Katô
Yoshiaki Horie

I. INTRODUCTION

As the result of dramatic rise of fuel cost, the development of extreme low head hydro potential by bulb turbines which was not utilized before are drawing a world-wide attention.

In India where there have been persistent shortages of power supply in the resent years, hydraulic power is being developed as well as thermal and nuclear powers in high pace as a countermeasure of the solution to this problem.

In India, there is two seasons a year; rainy and dry. Moreover, the ground is mostly flat and dry, so there are many irrigation channels with very slight slopes in many places. By utilizing this nature into consideration, power development with extreme low head hydraulic resources by bulb turbines is very much expected.

We would like to introduce hereafter "Western Yamuna Canal Hydro Electric Project" being developped by the Haryana State Electricity Board and "Lower Mettur Hydro Electric Project" by Tamil Nadu Electricity Board, as the latest and larger scale extreme low head hydraulic power development with bulb turbine-generators in India, for which we, Fuji Electric Co., Ltd. is now designing and manufacturing almost generating equipments required. The followings are the outline of the projects and main features of the bulb turbines and generators which are to be installed there.

Fig. 1 shows the locations of both hydro electric projects, and *Table 1* shows the technical features of turbines and generators.

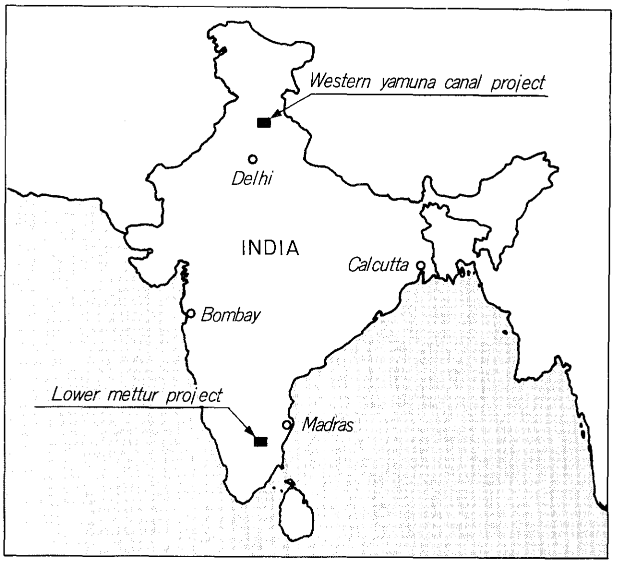

Fig. 1 Location of projects

II. WESTERN YAMUNA CANAL HYDRO-ELECTRIC PROJECT

1. Outline of the project

The Western Yamuna Canal Hydro Electric Project is located near the existing Tajewala Head works in Ambala District in the State of Haryana, about 215 km, North of Delhi, national capital of India. This project will be completed in two stages of development utilising 48 m head available between the Hathnikund Barrage (to be constructed newly) on the Yamuna River and Dadupur on the existing Western Yamuna Canal. Under Stage I, it is proposed to utilise about 38 m head available between the existing Tajewala Head works across the Yamuna and Dadupur on the Western Yamuna Canal by constructing an about 18 km long Hydel Channel taking off from the Western Yamuna Canal and three Power Houses on the Hydel Channel each operating under a head of 12.6 m and having an installation of 2 identical units of 8 M.W. each. In the second stage, utilising the drop available between the Hathnikund barrage and the Tajewala Head Works, one power house having two identical units of 8 M.W. each operating under a head of 9.45 m is installed. The project would operate on the run of the river basis and is expected to afford an annual energy generation of about 339 GWh from both stages in a dependable year and is operated in co-ordination with the power stations of the Northern Regional Grid.

Since this project is constructed in a sandy area, all the hydel channel will be covered with concrete tile in order to avoid loss of water by penetration. Also the power house uses a special construction which allows it to float on the sand.

Table 1 Main specifications of turbine and generator

	Name of Project	Western Yamuna Canal	Lower Metter
	Number of units	8 units (for 4 power plants)	8 units (for 4 power plants)
Turbine	Type	Horizontal bulb type turbular turbine (with movable guide vanes and runner blades)	
Turbine	Output (kW)	9,350 (Maximum)/7,310 (Rated)	17,200 (Maximum)/15,600 (Rated)
Turbine	Net Head (m)	12.8 (Maximum)/12 (Rated)	7.65 (Maximum)/6.5 (Rated)
Turbine	Discharge (m^3/s)	75 (Maximum)	271 (Maximum)
Turbine	Rated speed (rpm)	187.5	75
Turbine	Specific speed (m.kW)	716.5	902.5
Turbine	Runner inlet diameter (mm)	3,150	6,250
Turbine	Maximum momentary hydraulic pressure (m)	17.5	11.25
Turbine	Maximum momentary speed rise (%)	45	40
Generator	Type	Horizontal totally enclosed internal air cooling three-phase AC synchronous generator (with air coolers)	
Generator	Output (kVA)	10,440 (Maximum)/8,889 (Rated)	18,333 (Maximum)/16,667 (Rated)
Generator	Rated Voltage (kV)	6.6	6.6
Generator	Rated frequency (Hz)	50	50
Generator	Rated speed (rpm)	187.5	75
Generator	Rated power factor	0.9 (Lagging)	0.9 (Lagging)
Generator	Stator frame outer diameter (mm)	3,500	7,200
Generator	Type of excitation	Static thyristor type	Static thyristor type

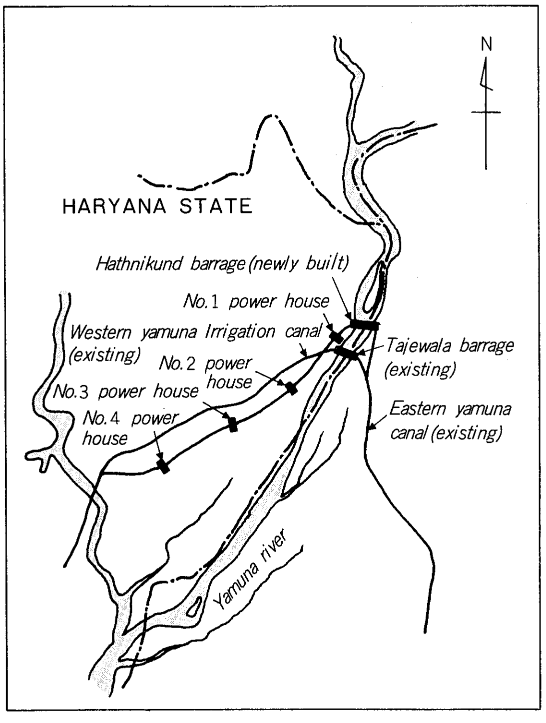

Fig. 2 Outline of Western Yamuna Canal project (Western Yamuna Canal)

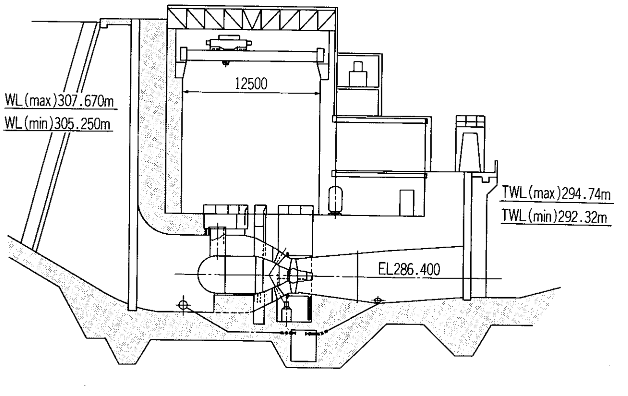

Fig. 3 Section of power house No. 3 (Western Yamuna Canal)

2. Structure and feature of turbine generator

For a bulb turbine-generator unit, coordination of turbine and generator is especially important and they must be treated as though they are one body. In the case of this machine, also, various examinations were made before finalizing the designs, including common features of both turbine and generator.

The following is a part of the results of these examinations; *Fig. 4* shows the sectional view of turbine and generator unit.

1) Flywheel effect(GD^2) and momentary speed rise

For bulb unit, outer diameter of the generator is, in general, minimized to dimensional limits of water passage decided by the relationship with the efficiency of the turbine. Because of this, GD^2 which the generator rotor

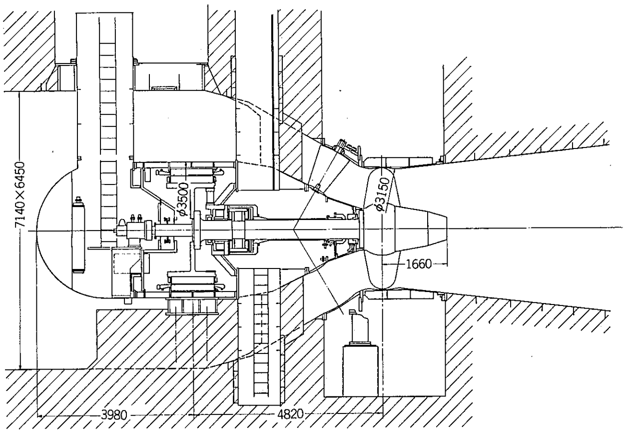

Fig. 4 Section of turbine and generator (Western Yamuna Canal)

posseses, will be small and accordingly, a higher momentary speed rise about 60% is normally adopted.

In case of this bulb unit, however, it was judged that flywheel effect (GD^2) of more than 175t.m^2 would be required for operational transient stability of the machine on fault of the grid systems, and therefore a stator iron core of bigger outer diameter was adopted to the generator without reducing the turbine's efficiency, in other words, keeping the generator's outer diameter small, to fulfil this requirement. As a result, the maximum momentary speed rise became as low as 45% when full load rejected suddenly.

2) Supporting structure of bulb

The bulb which accommodates a generator is supported by two upper and lower stay-vanes installed on the turbine casing, and by a pier provided under the bottom of the stator frame of the generator.

Various loads such as hydraulic water thrust, generator short circuit torque, dead weight, bouyancy, vibration during operation and heat expansion in the generator etc. act to the bulb assembly. And among them, hydraulic water thrust toward the axial direction is absorbed by the turbine stay vanes, and generator short circuit torque is shared by both the generator's pier and turbine stay vanes.

For this reason, the pier is so constructed that the displacement of the generator stator frame is free only torward the axial direction to follow the deformations of the stay vanes and heat expansions of the stator frame.

3) Number of bearings and their arrangements

Considering the bending of the shaft, critical speed, maintenance, etc., two guide bearings are arranged as shown in *Fig. 4* so that the rotor of the generator is overhung.

Thrust bearing is installed together with the generator side guide bearing. The bearings are supported by the inner casing having a high rigidity, so that deformation of bearing support is kept minimum and that load on each thrust bearing pad is kept balancing even if a heavy hydrualic thrust acts on it.

A forced oil supply system is adopted for the lubrication of the bearings. This system has a lubrication oil head tank used commonly with the turbine bearing.

4). Structure of turbine

Turbine casing consists of a cone shaped inner and outer casings, and both casings are connected with upper and lower stay vanes. The casing is delivered in five divided pieces to be assembled and welded to one unit at the site.

A part of the hydraulic thrust force and generator short circuit torque which acts to the bulb is transmitted to the foundation concrete of the power house through the inner casing and stay vanes.

Inside of the stay vane is hollow and this space becomes access for assembling, disassembling, and checking of bearings and other components of turbine and generator, as well as for installations of the pipes, cables and wires.

The cone shaped draft tube liner is of welded steel plates, and the liner is supplied up to the point where water

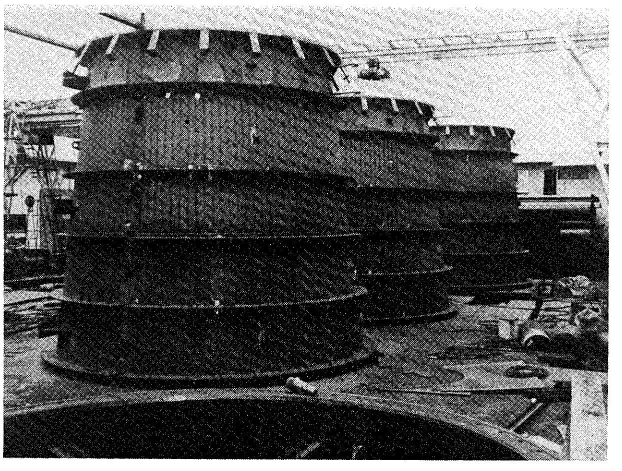

Fig. 5 Draft tube liners, trial-assembled at shop (Western Yamuna Canal)

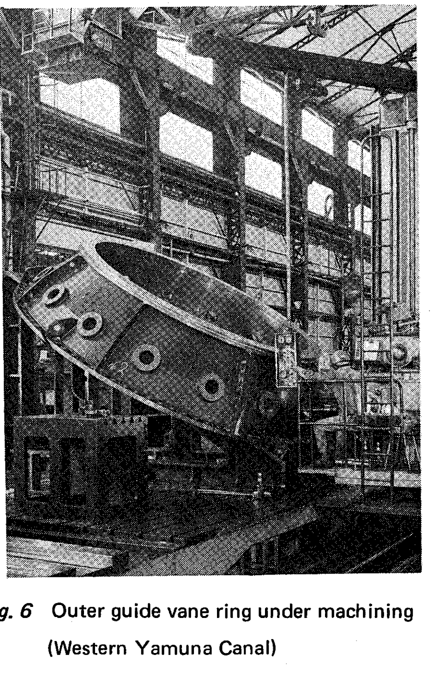

Fig. 6 Outer guide vane ring under machining (Western Yamuna Canal)

flow velocity is reduced to 5 m/s.

Guide vane is made of cast steel and is overlaid with 18-8 stainless steel on the important portions, and sixteen pieces of the guide vane are lined up in a conical shape between inner and outer distributor cones.

In the case of a bulb turbine, the bulb portion which is placed in water passage is accompanied by a large displacement toward axial direction during the operation. Accordingly, spherical bearings are employed for the guide vane so that it will not effect the smooth operation of the guide vane even if the bulb displaces toward the axial direction.

For each bearing of the guide vane regulating mechanism, a solid lubricant buried type non-grease lubricated bearing is adopted to simplify the maintenance.

An eccentric pin is used to adjust the shutter face gap between guide vanes, and a weak-point link is adopted in the guide vane link mechanism, and an alarm system is provided to detect a breakage of the weak-point link.

The guide vane is operated by a hydraulic oil double acting servomotor during normal operation, and in an emergency case like oil pressure failure, it is closed automatically by a counter weight provided in the guide vane regulating ring.

Guide vane regulating ring is supported in its position by special bearing using ball bearings.

The turbine bearing is of cylindrical type. Since the runner is installed on the shaft in overhang, special consideration is given to design of the bearing support so that the bearing can tilt following the tilted main shaft to avoid a one-side contact of the bearing.

The mian shaft sealing device is of self-adjusting, axial movement, carbon packings type for which its excellent sealing characteristic has been proved by abundant installations supplied by Fuji Electric.

The runner has 3.15 m diameter and four(4) blades of 13% chrome high nickel stainless steel.

The runner servomotor is installed inside of the runner hub, using the system in which the piston is fixed and the cylinder moves.

The pressure oil to operate runner servomotor is supplied from the oil pressure feeding device provided on the upstream side of the generator auxilialy shaft, through the oil pressure leading pipes installed in the shafts.

5) Structure of the generator

Cooling air in the generator is circulated by motor operated fans and self-ventilation fan mounted on downstream side of the rotor as shown in *Fig. 7*.

A part of the cooling air forced by the motor operated fans enters the stator directly through the space between poles in the upstream side, another part of the cooling air enters the stator from the space between poles in the downstream side after passing through the rotor center, and then led to the top cover in which air coolers are installed, through the air duct provided on outer periphery of the stator core.

For the cooling of the slip ring, a part of the main cooling air is led to the slop ring chamber and after filtered, returned to the main cooling air circuit.

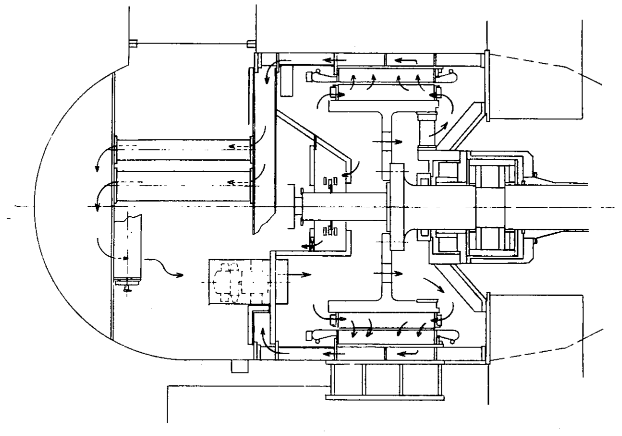

Fig. 7 Cooling system of generator (Western Yamuna Canal)

The stator is assembled completely with cores and coils at the shop and shipped in one piece.

For the insulation of stator windings, totally vacuum impregnated insulation system (so called F resin/G insulation) mainly using epoxy resin is adopted.

With this system, the whole windings and the iron cores are vacuum-impregnated with epoxy resin and hardened together, improving the insulation performance. Further, the mechanical rigidity is increased very much, and heat transfer is improved as the space between the iron core and coils is filled with resin.

The rotor consists of poles and rotor center, and is overhung on the main shaft. The poles are attached by bolts on the rotor center and are shipped after being assembled in a single unit at the shop.

In the inner side of the rotor center, a brake having a sufficient capacity against a leakage water torque is installed.

Stator coils and rotor poles can be repaired or replaced without removal of the rotor.

Moreover, for the main components in the bulb casing, considerations are given to the divided numbers of each component and dimensions of the access shaft so that the components can be taken out turough the access shaft in both the up- and down-stream sides without detaching the pipings and wirings.

For bulb turbines and generators installed in water passage, preventions for leakage water into the bulb is most important. For this machine, the stator frame is constructed as one complete assembly so as to reduce split flange faces of the bulb, and at the same time, double O-rings are provided in the flange faces of the generator stator to the top cover and the inner turbine casing. Moreover, a groove is provided between the double O-rings, so that water leakage can be detected and water tightness can be backed up by sealing the groove with a special packing in the event a water leakage is detected.

At the very bottom of the top cover, a device to

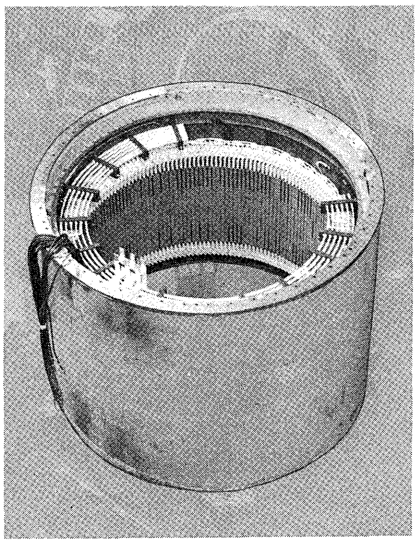

Fig. 8 Generator stator under manufacturing (Western Yamuna Canal)

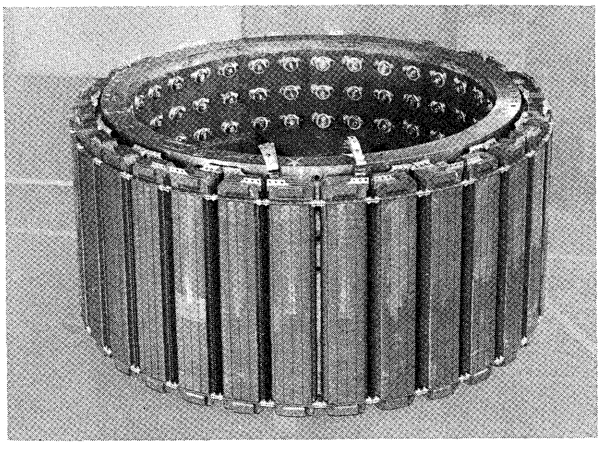

Fig. 9 Shop assembly of rotor (Western Yamuna Canal)

predict and drain leaked or condensed water is installed, and a dehumidifier is also set in the top cover to prevent condensation of moisture in the machine when it is not in operation.

III. LOWER METTUR HYDROELECTIRC PROJECT

1. Outline of the project

This project is located in the Salem district, in the western part of Tamil Nadu State, in South India.

It utilizes a 36 m head available in distance of about 45 km long between the existing power station tailrace outlet just below the Mettur dam in the upstream of Cauvery River and downstream of Bhavani point.

Four barrages are built in cascade on the river at nearly equal distance and a power house is built accomodating two identical 15 WM bulb turbine-generators at each barrage, thus total generating output of this project becomes 120 MW (15 MW x 2 x 4).

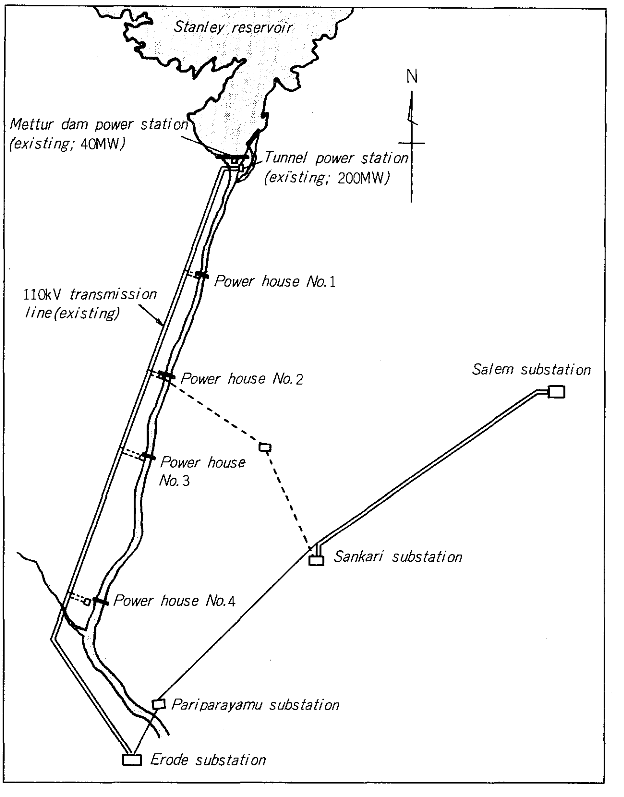

Fig. 10 Outline of Lower Mettur project

In the area where this project is being developped, water flow is less available for electric power generation during the dry season. Therefore, in some turbine generaing units, generator is operated as a rotary synchronous condenser in the dry season after draining water from the water passage to improve power factor and to stabilize voltage and frequency of the power grid system.

The generated voltage is stepped up by the main transformer in each power house, and then transmitted to substations in the vicinity through the existing and newly installed 110 kV transmission lines.

In *Fig. 10.*, Outline of this project, in *Fig. 11.*, section and plan of the power house and in *Fig. 12.*, excavation work of No. 3 power house are shown.

2. Structures and features of turbine and generator

The machine is basically of the same structure as the one for Western Yamuna Canal Project. But due to a large size of machine, the design and manufacture are being proceeded with due consideration of not only rigidity and deformation of bulb unit but also readiness of installation and maintenance.

Cross-sectional view of the turbine generator is shown in *Fig. 13*.

Main features of the machine and different points as compared to the machine for Western Yamuna Canal Project are introduced below.

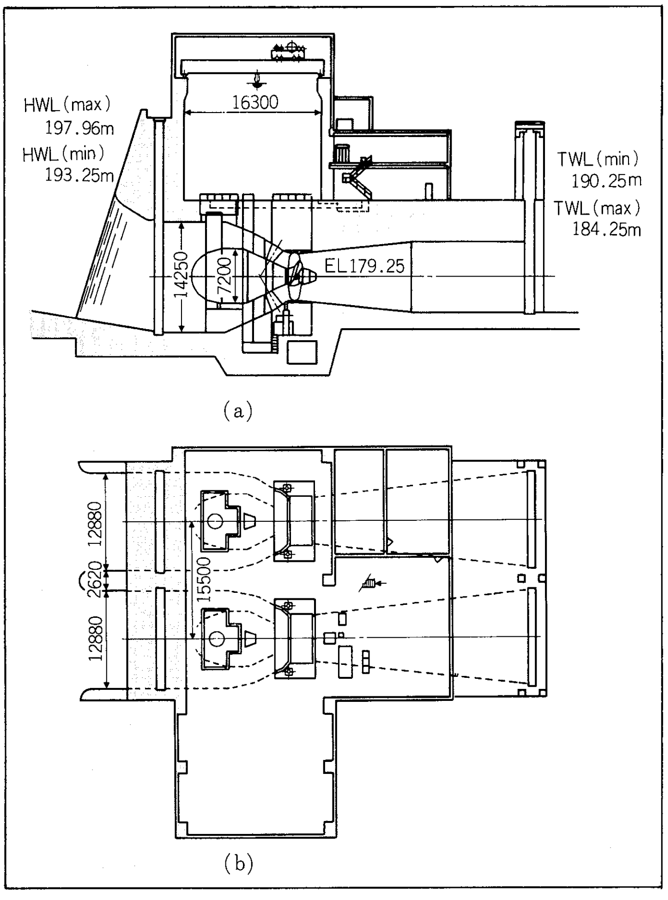

Fig. 11 Section and plan of power house No. 1 (Low Mettur Project)

Fig. 12 Excavation work at power house No. 3 (Low Mettur Project)

1) Maximum momentary speed rise.

Based on analysis of dynamic machine stability, flywheel effect (GD^2) more than 2500 tm^2 and transient reactance (X'd) under 30% were required. Therefore, the maximum momentary speed rise of 40% which is an extreme low value as for a bulb turbine generator was adopted.

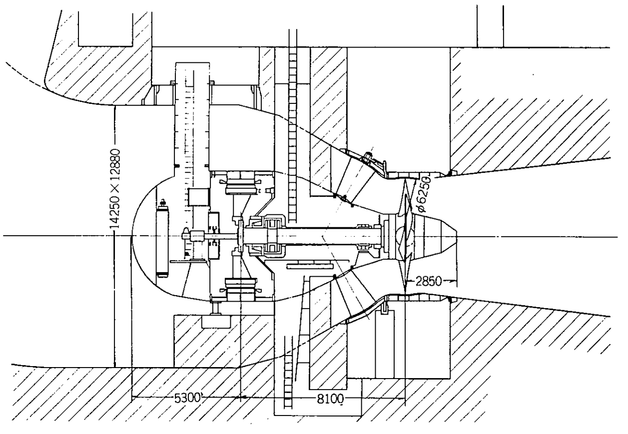

Fig. 13 Section of turbine and generator (Low Mettur Project)

2) Supporting structure of bulb

The bulb is supported mainly by the two upper and lower stay vanes as in the case of Western Yamuna Canal Project.

However , since the machine is of an extreme low head and huge size, the displacement amount of the various parts of the bulb naturally increases. Therefore, beside the supporting base in the generator bottom, two supporting arms are provided to prevent the generator swing toward the horizontal direction.

Further, a special structure enabling to follow the displacement of the bulb in the axial direction and radial direction has also been adopted for the supporting base and arms. Also same consideration have been given to the construction of guide vane bearings for these displacements.

3) Oil lifter

The lubrication system for bearing is of a forced oil feeding type using the head tank.

However, due to huge size of machine, oil lifter pump is provided to make lubrication effective for guide bearings, during starting and stopping of the machine, though the bearing itself has an enough capacity to stop the machine safely even if the oil lifter pump is out of service.

4) Turbine

The runner is 6.25 m in diameter and have four(4) movable blades of 13% chrominum high nickel stainless steel.

Since this machine is operated at extreme low head site, studies and investigation were made for both cases of runners having four blades and three blades as shown in *Table 2*.

However, four blades runner was finally adopted since there is no proven record of actual operation of three blades runner in the world at that stage.

In the future project, such as for an extreme low head project like Lower Mettur Hydro Project, it is expected that three blades runner is most likely to be used.

Outer casing of the turbine is shipped after being divided into eight pieces, and is reassembled at the site by welding and flanged connection. The inner turbine casing is

Table 2 Comparison by runner blade numbers

Nos. of runner blade		4	3
Runner diameter	(mm)	6,250	6,000
Rotating speed	(rpm)	75	83.3
Suction head (based on turbine center level)	(m)	−5.0	−7.0
Ratio of maximum efficiency (including generator efficiency)		1.0	0.993
Ratio of total weight of turbine-generator		1.0	0.93

of a 2-split flange connecting structure. The stay vanes and outer casing are connected by welding at the site.

As in the past, hatch cover and hatch frame were embedded into secondary concrete to be placed in the blocked-out pit which was provided in the primary concrete, being held with temporaly heavy supporting materials.
cover and hatch frame in the pit were fixed and supported.

However in this project, method is adopted to support the hatch cover and frame with primary concrete, making easier installation of the hatch without necesity of any other temporaly supporting materials.

Welded steel plate construction is applied for the guide vane. In case of the low head and large size machines, welding structure has been adopted often for the guide vanes of vertical shaft machine.

For the guide vane having a complicated shape like of the bulb turbine, welding structure is also superior in view of quality (against casting products) and easier handling (reduction in weight), etc., in case of huge size unit.

5) Generator

Stator frame is shipped in two pieces with flanged joints, due to the limitation for the transportation.

Then, after being assembled with flanges at the site, outer periphery of the joints are seal-welded.

Stator core is stacked at the site so as to be constructed as a seamless single ring, and is fixed to the stator frame with dovetail keys.

For the stator winding, Fuji Electric's standard F resin/S insulation, using prepleg material mainly consisting of samica and epoxy resin is adopted.

Rotor center is of welded steel plates and is mounted on the main shaft in overhung.

Thin steel plates laminated structure is employed for the yoke, and by providing the ventilation ducts in the yoke, cooling effect is being improved.

The yoke is shrinkage-fitted to the rotor center, and consideration is made so that the repeated stress does not work on the parts.

Pole core is of laminated steel sheet construction and is attached to the yoke by dovetail keys.

For rotary condenser operation required during the dry season, half voltage self starting method is adopted by using mid-voltage tap of the main transformer. Therefore, the damper winding is designed and constructed by taking thermal and mechanical stress at the time of condesnser starting into considerations.

The brake is installed in the down stream side of the rotor and has enough capacity against leakage water torque.

The position of the brake of a huge machine can be freely selected. For the machine, it has been finaly selected in consideration of the maintenance space in the bulb so that easy maintenance can secured.

IV. POSTSCRIPTS

We have introduced an outline of the latest and larger scale, extreme low head hydroelectric power generating projects in India. It is of our proud that, with completion of these important projects, we will be able to contribute to development of both economy and industry in India.

We hope that this article will be of assistance to the oncoming projects of extreme low head hydroelectric power developments.